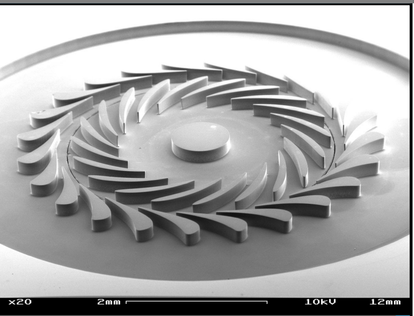
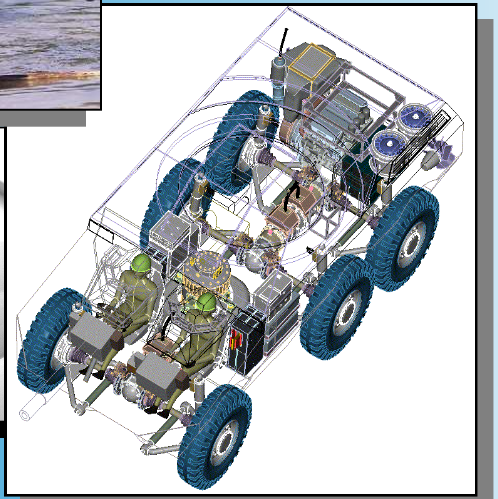




Collaborative Technology Alliance (CTA)

Power & Energy (P&E)

John Hopkins
ARL Collaborative Alliance Manager

Honeywell

Dr. Mukund Acharya
Consortium Manager, Honeywell Engines, Systems & Services

Power and Energy Collaborative Technology Alliance

Consortium Partners

- Honeywell
- MIT
- Clark Atlanta
- Georgia Tech
- U of Maryland
- Motorola Labs
- NuVant Systems
- Case Western Res U
- Illinois Inst of Tech
- Penn State Univ
- Tufts Univ
- U of Minnesota
- U of New Mexico
- U of Pennsylvania
- U of Puerto Rico
- U of Texas – Austin
- SAIC
- Rockwell Scientific
- United Defense LP
- Prairie View A&M
- Rensselear Polytechnic

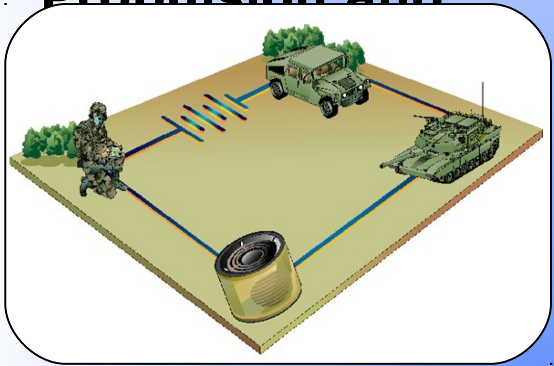
Objectives

Research and develop technologies that enable lightweight, compact power sources and highly power dense components that will significantly reduce the logistics burden, while increasing the survivability and lethality of the soldiers and systems of the highly mobile mounted and dismounted forces of the Army's Objective Force.

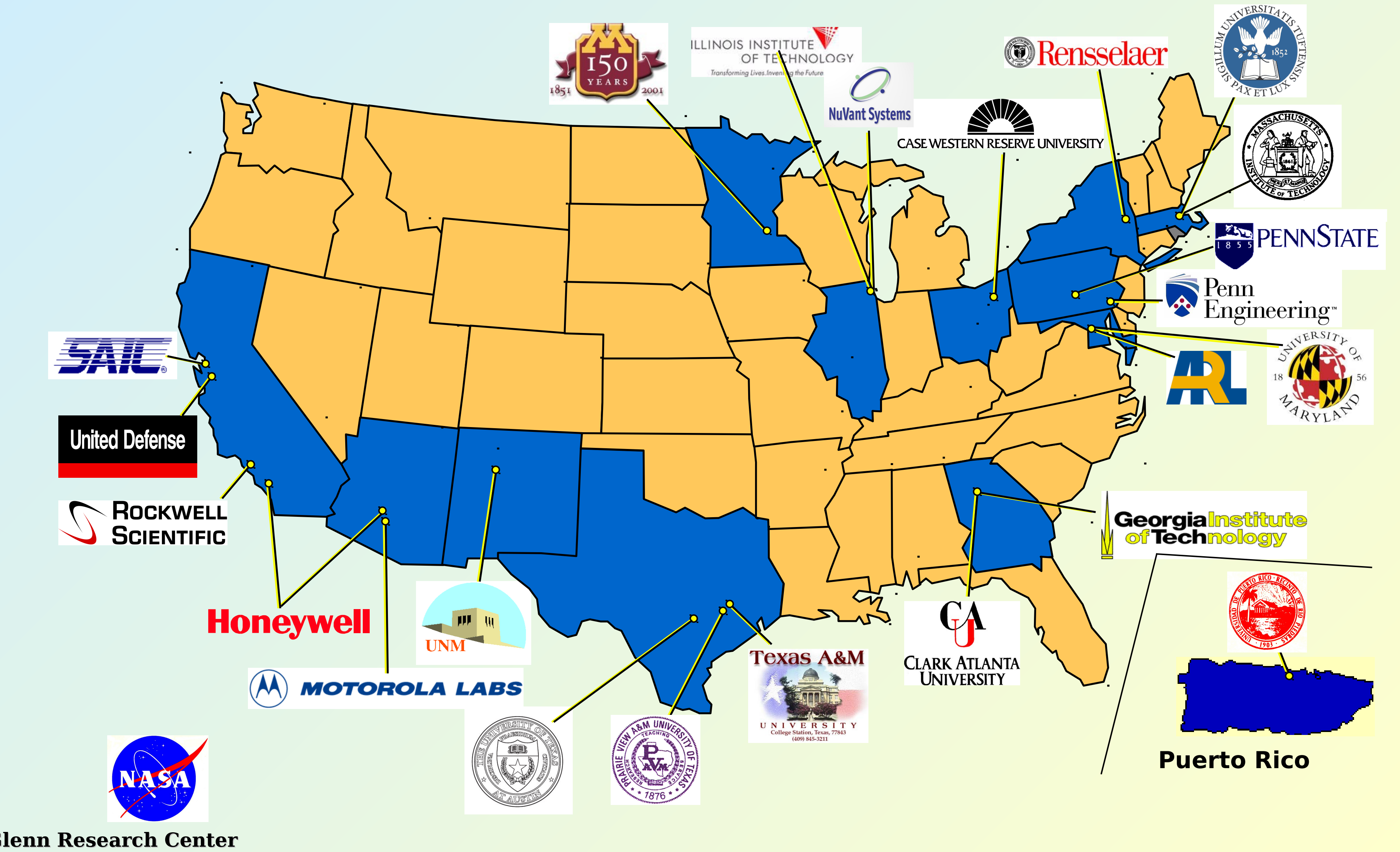
- Air-breathing, fueled compact power sources
- Reformate fuels for power systems
- Highly power dense, high temperature power

Technical Areas

- Portable, Compact Power Sources (Non-electrochemical)
- Fuel Cells and Fuel Reformation
- Hybrid Electric Propulsion and



Power and Energy Collaborative Technology Alliance



P&E Alliance Vision & Program Requirements

Objective:

- Support the Army's vision for the Objective Force Warrior, Future Combat System and the Objective Force.
- Conduct research and technology development to enable compact & efficient power and propulsion systems required to assure a survivable, affordable air-insertable, sustainable combat force with a small logistic footprint.
- Enable future army capability to put a self-sustaining force anywhere in the world within 96 hours after lift-off, a war-fighting division on the ground in 120 hours and five divisions in 30 days.

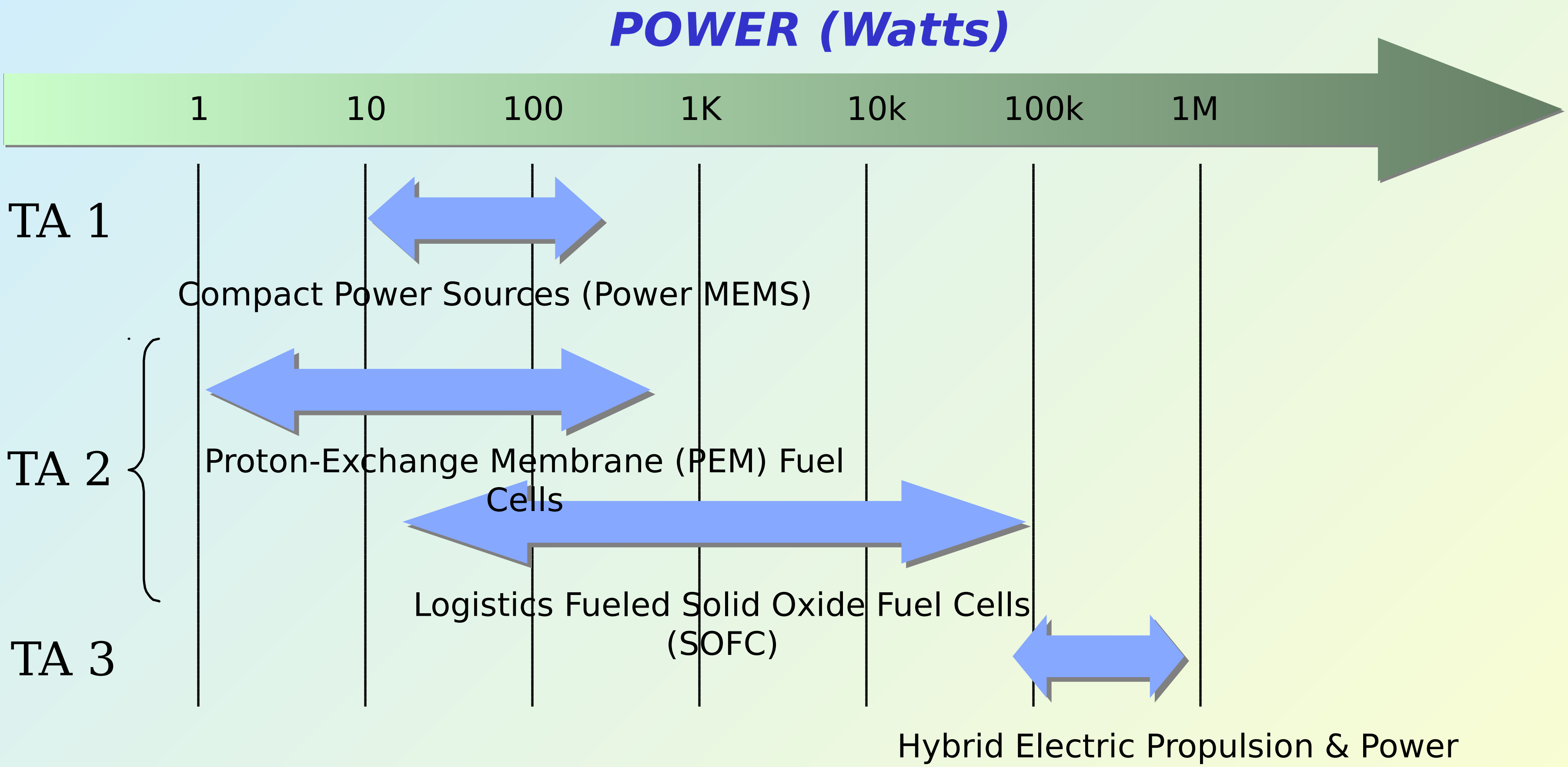
Technical Challenge:

- Define and develop required lightweight, compact, power and fuel-efficient technologies.

- Increase the energy density of compact soldier portable power systems by 5-10 times over current level of 200 W-hr/kg

- Increase the energy density of vehicle propulsion systems by 3-5 times over current diesel engines while reducing usage of fossil fuel by 75%.

Three Focus Areas for Research & Technology



- Portable Compact Power Sources (non electrochemical)
- Fuel Cells & Fuel Reformation
- Hybrid Electric Propulsion & Power

Power and Energy Collaborative Technology Alliance

PM: Honeywell ES&S, Dr. Mukund Acharya

CAM: ARL, John Hopkins

CAM: ARL, John Hopkins

Portable Compact Power Sources

MIT, Dr. Alan Epstein
ARL, John Hopkins

- MEMS Magnetic Generators
- Microfabrication Technology
- MEMS Gas Turbine Generators

Fuel Cells & Fuel Reformation

Motorola, Jerry Hallmark
Honeywell, Dr. Nguyen Minh
ARL, Dr. Deryn Chu

- DMFC Catalysts
- Polymeric Membranes
- DMFC Design, Model, Prototype
- RHFC Catalysts and Support
- High-temp MEA
- RHFC System

- Low-temp SOFC Materials
- Direct Hydrocarbon reforming anode
- SOFC Cell Fab, Eval, Testing
- Logistics Fuel Reformation Catalysts
- Hi-temp Fuel Desulfurization
- Logistics Fuel Reformation CPOX & Desulfurization

Hybrid Electric Propulsion & Power

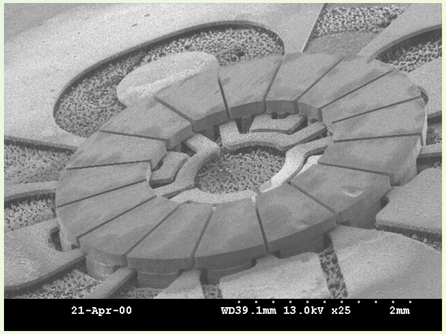
SAIC, George Frazier
Honeywell, John Meier
ARL, Dr. Ken Jones

ARL, Dr. Ken Jones

- Hi-speed Ceramic Turbogenerator
- Turbo-electric compounded diesel
- Matrix Converter
- DC/DC Converter
- SiC Materials/Devices
- Electric Machines
- Systems Analysis

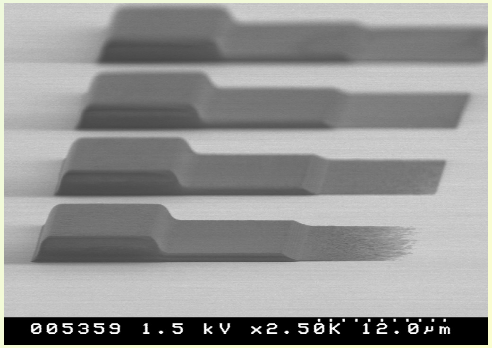
P&E TA 1: Portable, Compact Power Sources (Non-electrochemical)

Objective: Provide enabling technologies for revolutionary non-electrochemical soldier power sources, having 10X greater energy density than current batteries and capable of meeting the power and energy requirements of the Objective Force Warrior.



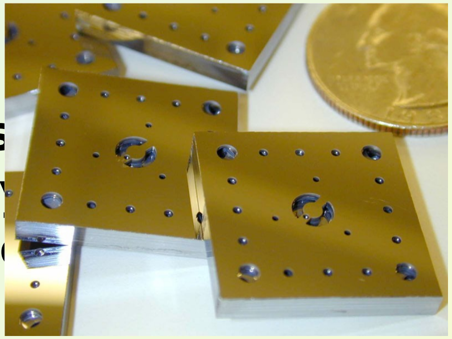
Challenges:

- Achievement of acceptable energy conversion efficiency
- Precision microfabrication and alignment
- Microfabrication of high temperature materials
- Incorporation of battlefield robustness and low signature emission

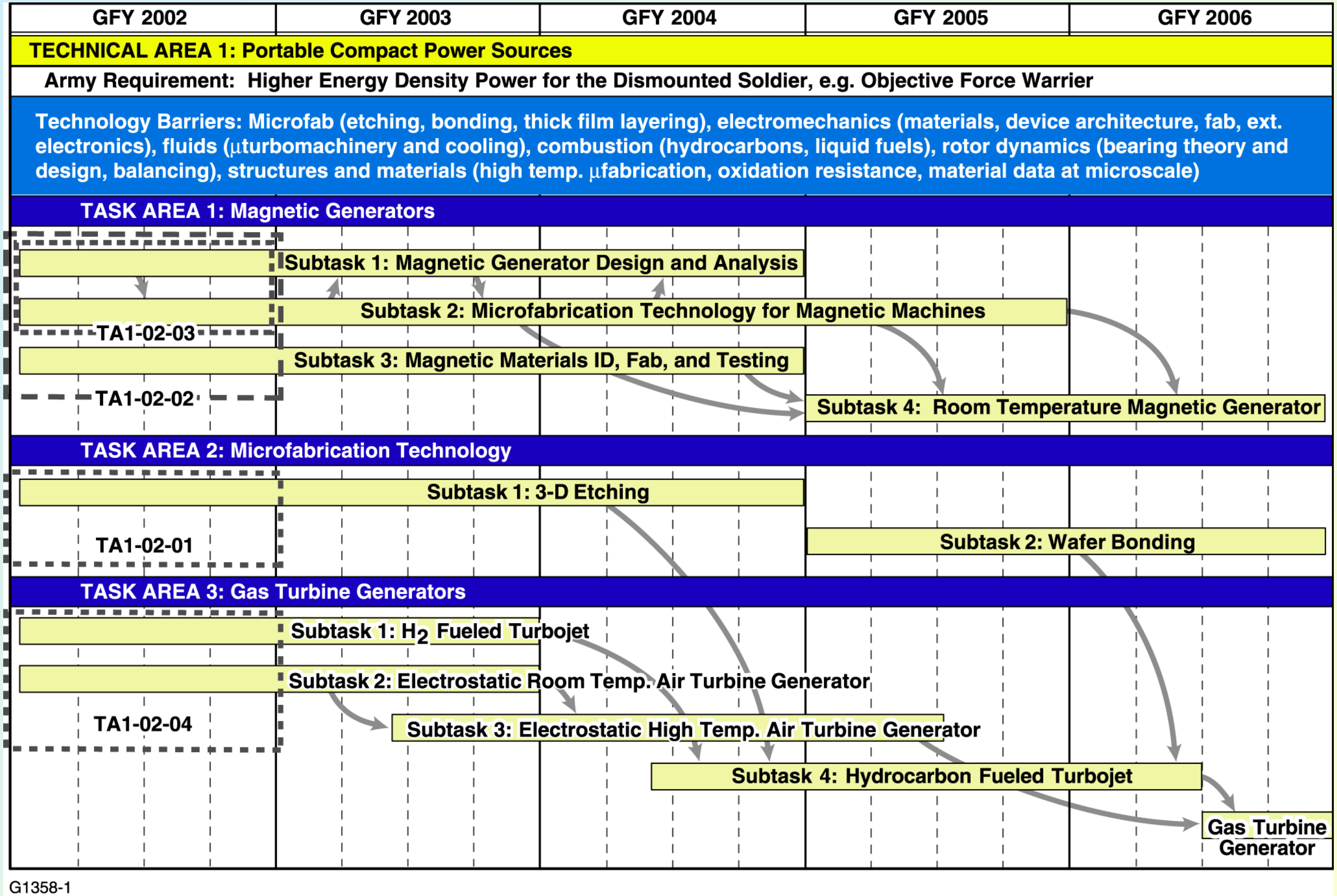


Research Tasks:

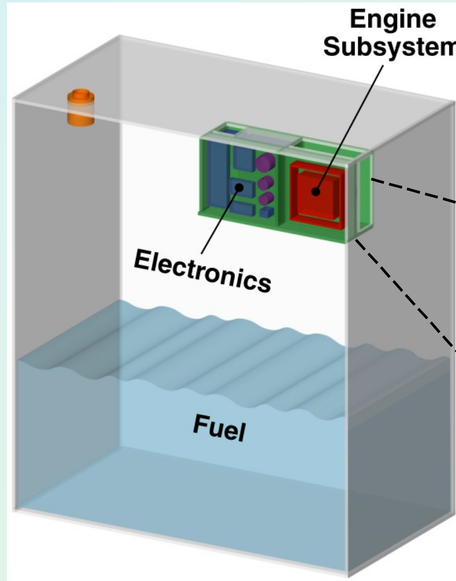
- MEMS Magnetic Generators
- Microfabrication Technolog
- MEMS Gas Turbine Generat



Portable, Compact Power Sources Five-Year Research Roadmap



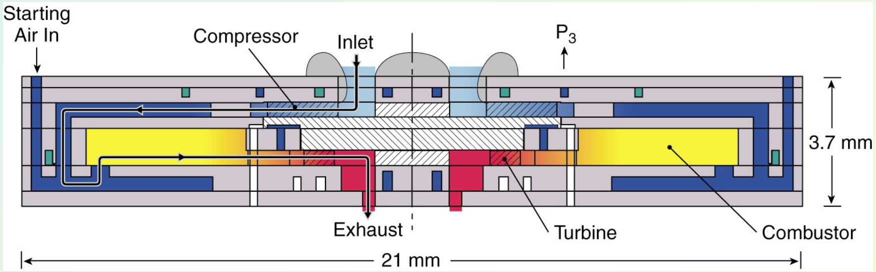
Portable Compact Power Sources
– MEMS Gas Turbine Generator –

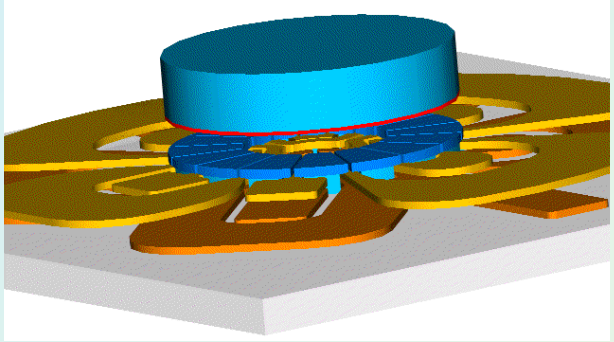


- **Approach**
  - Simple cycle gas turbine
  - Direct drive generator (1.2M RPM)
  - MEMS fabrication
- **Near-term performance goals**
  - 5% efficiency (chemical to electrical)
  - 1-10 watts output
- **FY02 major milestones**
  - First gas turbine operation
  - First air turbine electric generator power production

Portable Compact Power Sources
– Basic Research Team –

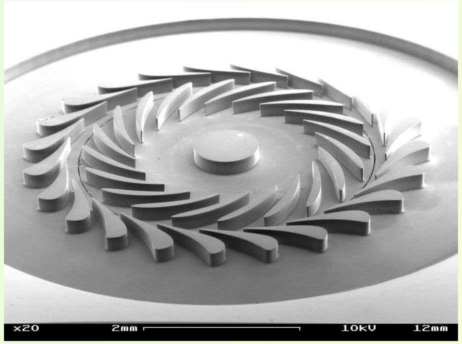
MIT
Gas Turbine & Electrostatic Generator





Georgia Tech
Clark Atlanta
Electromagnetic Generator

U. of Maryland
Microfab Technology



Portable, Compact Power Sources
FY '02 Annual Program Plan

Portable Compact Power Sources

MIT, Dr. Alan Epstein
ARL, John Hopkins

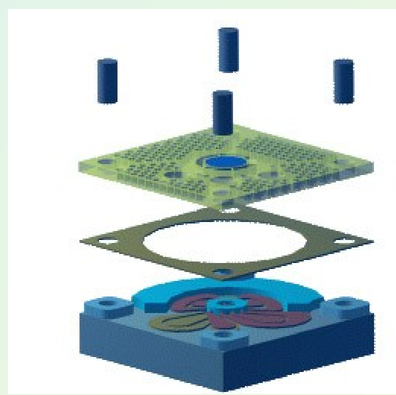
MEMS Magnetic Generators

Microfabrication Technology

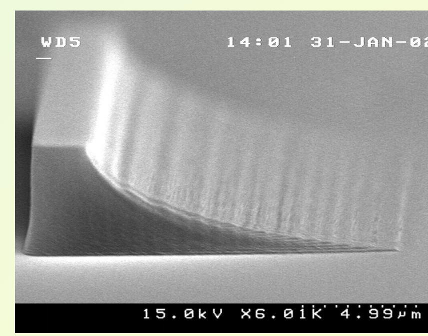
MEMS Gas Turbine Generators

First Gas Turbine Tests

First Low Temperature Electric Generator Tests



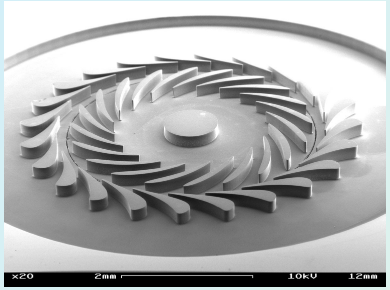
Improved Magnetic Machine Designs & Technology



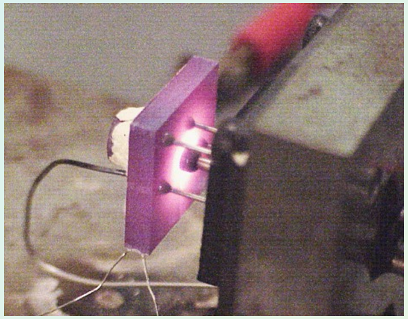
3-D Microfab Technology

Portable Compact Power Sources
– Gas Turbine Generator Current Status –

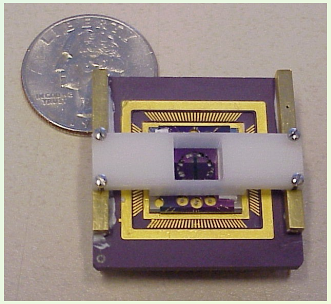
- Many components demonstrated, for example



Bearings & Turbine

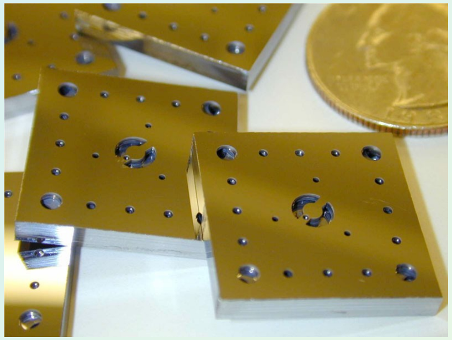


Combustor

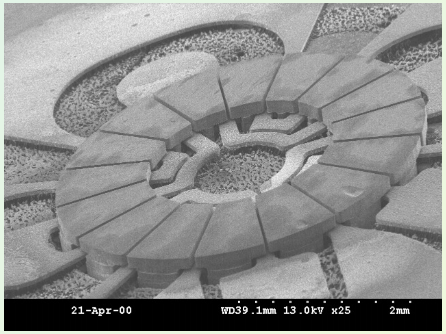


Electromechanics

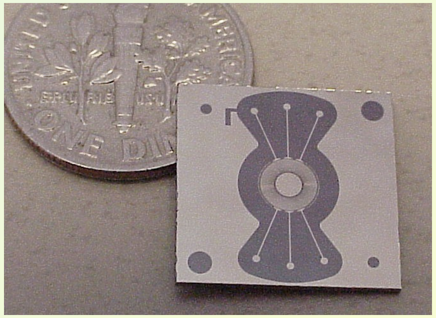
- Micro device testing planned for FY 02



1st Gas Turbine Engine



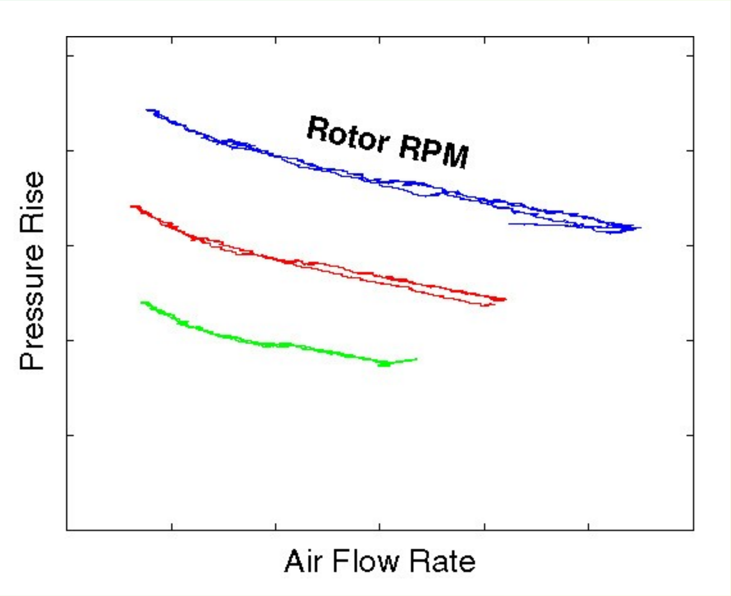
Magnetic Motor



1st Generator

Portable Compact Power Sources
– Engine Testing Started –

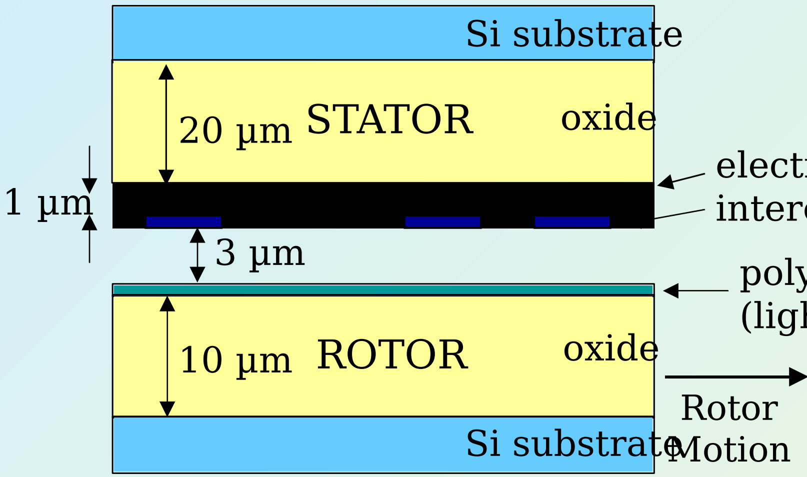
Engine Cutaway
Showing Compressor Rotor



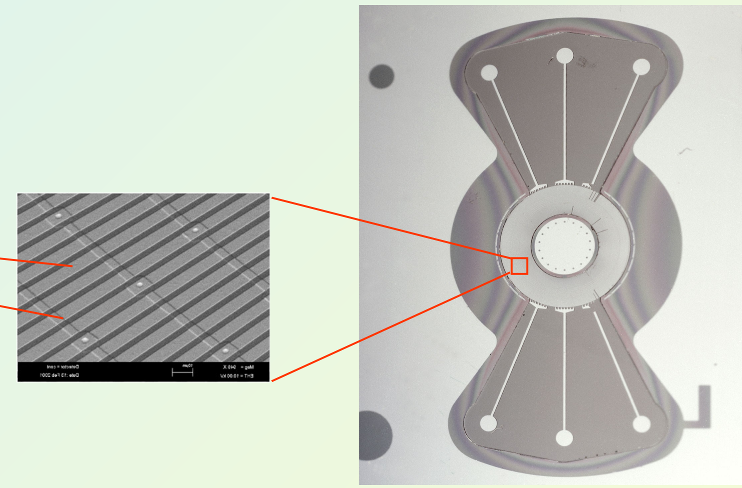
Measured Compressor Map

Portable Compact Power Sources
– Electrostatic Induction Motor-Generator –

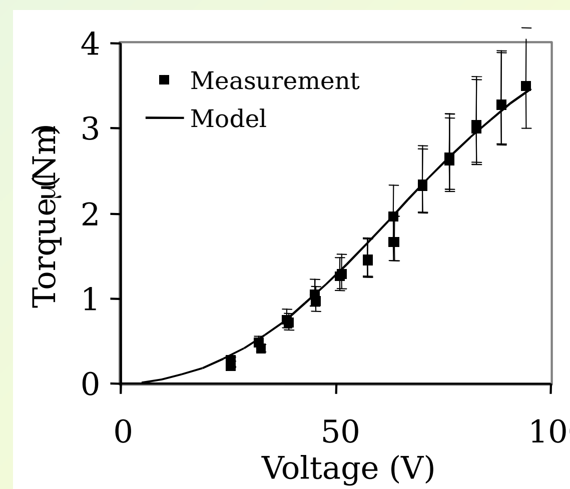
Design Concept



4 mm dia Stator

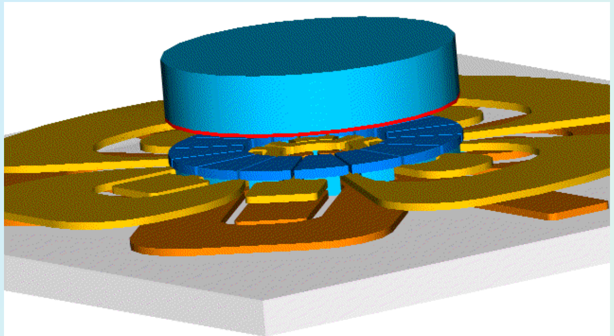


Device diameter = 4.0 mm
786 electrodes grouped in 6 phases
Electrode voltage = 300 V peak
Electrical frequency = 1.5 MHz
Mechanical frequency = 1 Mrpm

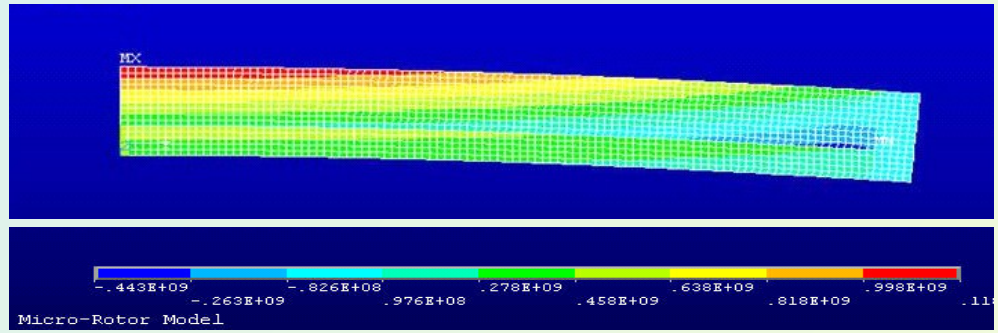


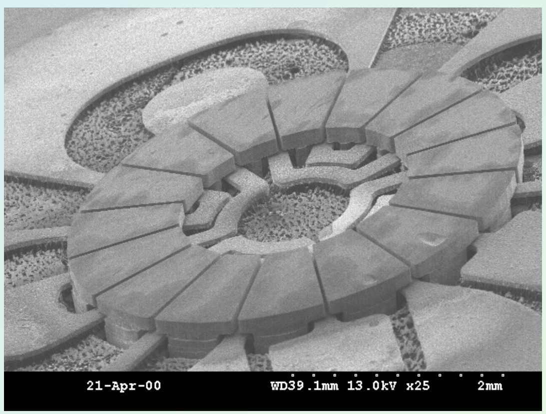
Model Verification

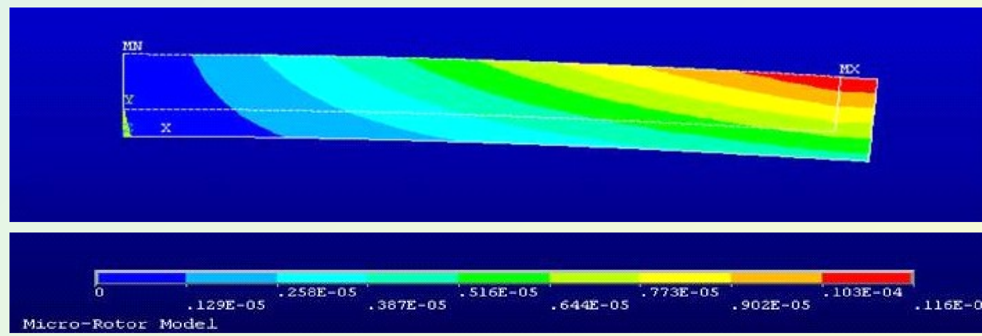
Portable Compact Power Sources
– Magnetic Generator Progress –



System Design (MIT)







Rotor Structural Analysis (CAU)) indicates high speed rotors are feasible

Solid Stator shown (GIT)
Laminated version in progress

Portable, Compact Power Sources
FY '03 Proposed Tasks

Portable Compact Power Sources

MIT, Dr. Alan Epstein
ARL, John Hopkins

MEMS Magnetic Generators

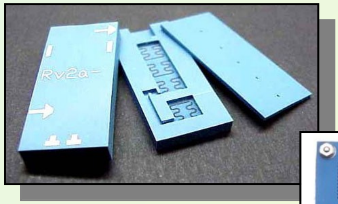
Microfabrication Technology

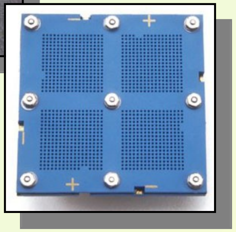
MEMS Gas Turbine Generators

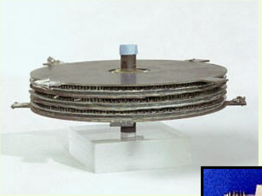
- **Turbojet engine**
  - High power testing
  - Component improvements
- **Electrostatic generator**
  - High power testing of room temp. unit
  - First tests of high temperature unit
- **Magnetic generator**
  - Subcomponent demonstrations
- **Microfabrication technology**
  - Variable height compressor & turbine

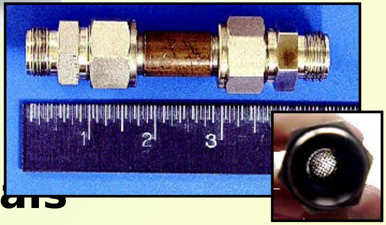
P&E TA 2: Fuel Cells and Fuel Reformation

Objective: **Provide enabling technologies for soldier portable fuel cell systems, including fuel processing for hydrogen generation and storage. Provide enabling technologies for logistics fuel reformation and fuel cells for vehicle propulsion.**









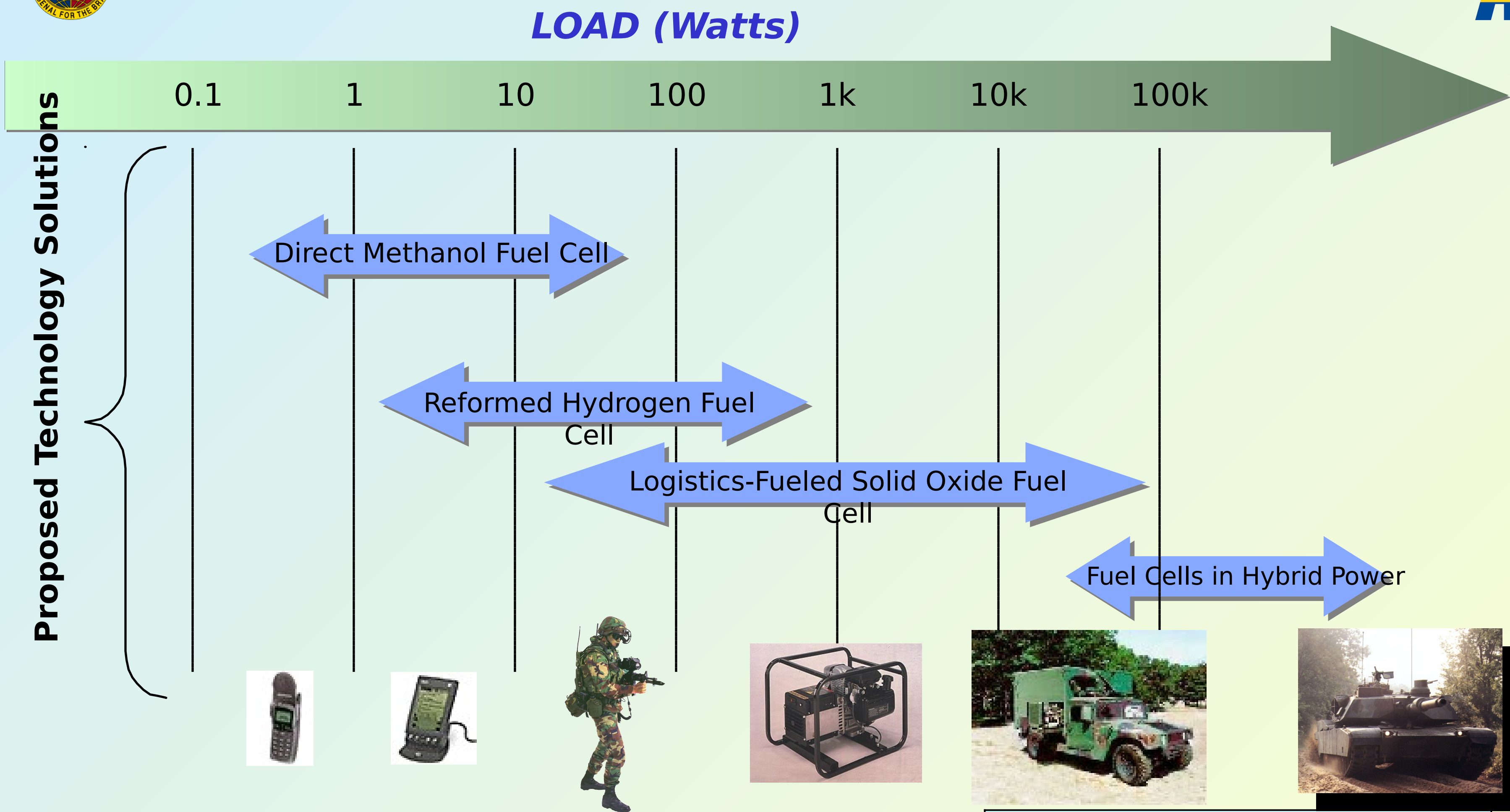
Challenges:

- **Battlefield robustness, including load following and temperature extremes**
- **Rate controlling catalytic chemical processes**
- **H_2 storage and/or microreforming of fuel**
- **Improved electrocatalysts, electrolytes for DMFC**
- **Range and variation in logistics fuel constituents: high sulfur content, etc.**

Research Tasks:

- **DMFC Catalysts**
- **Polymeric Membranes**
- **DMFC design, model, prototype**
- **RHFC Catalyst and Support**
- **High-Temp MEA**
- **RHFC System**
- **Low-temp SOFC Materials**
- **Direct Hydrocarbon Reforming Anode**
- **SOFC Cell Fab, Evaluation, Testing**
- **Logistics Fuel Reformation Catalysts**

Power Solutions with Fuel Cells



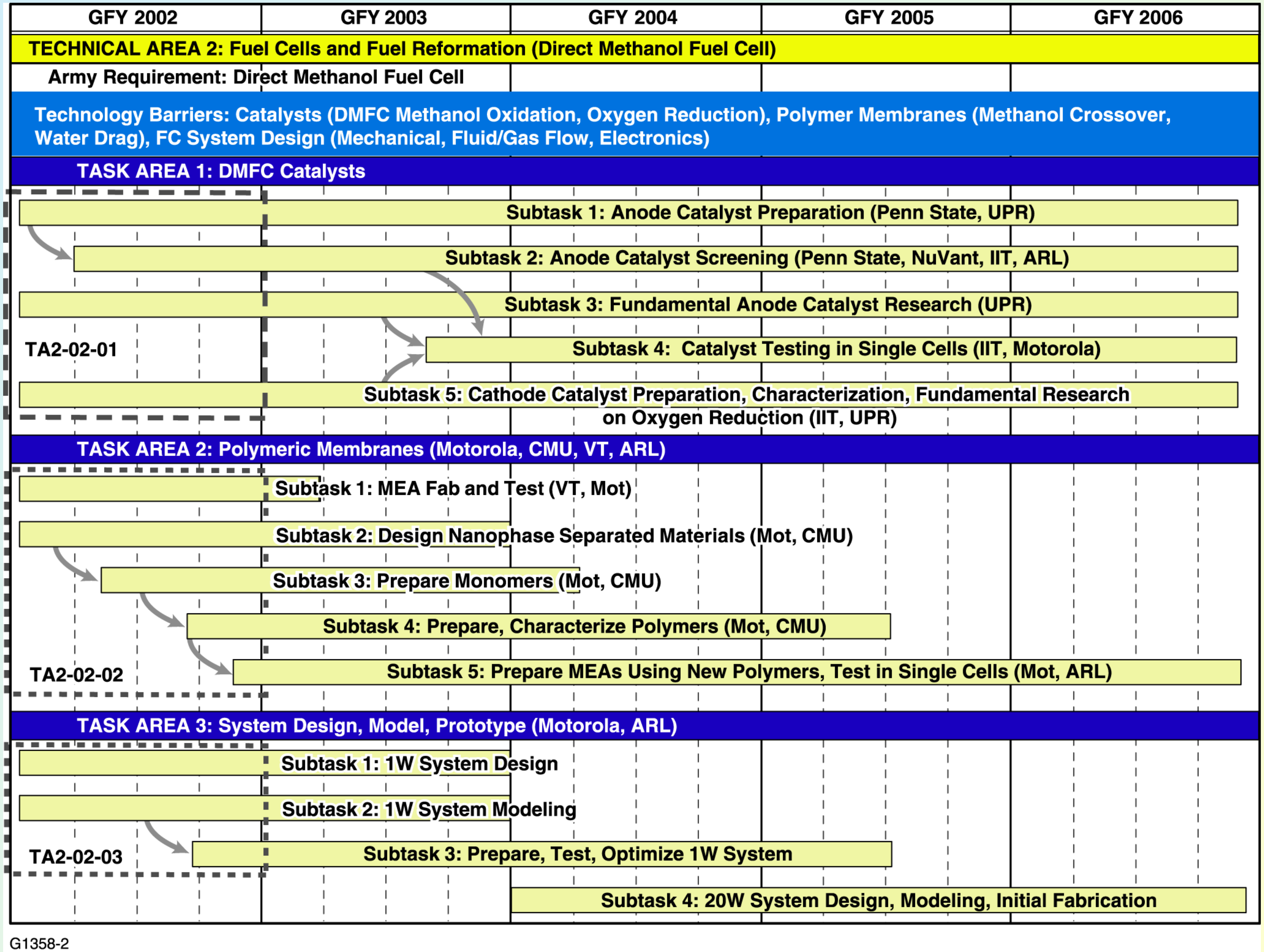
Direct Methanol Fuel Cells (DMFC)

Reformed Methanol to Hydrogen Fuel Cell (RHFC)

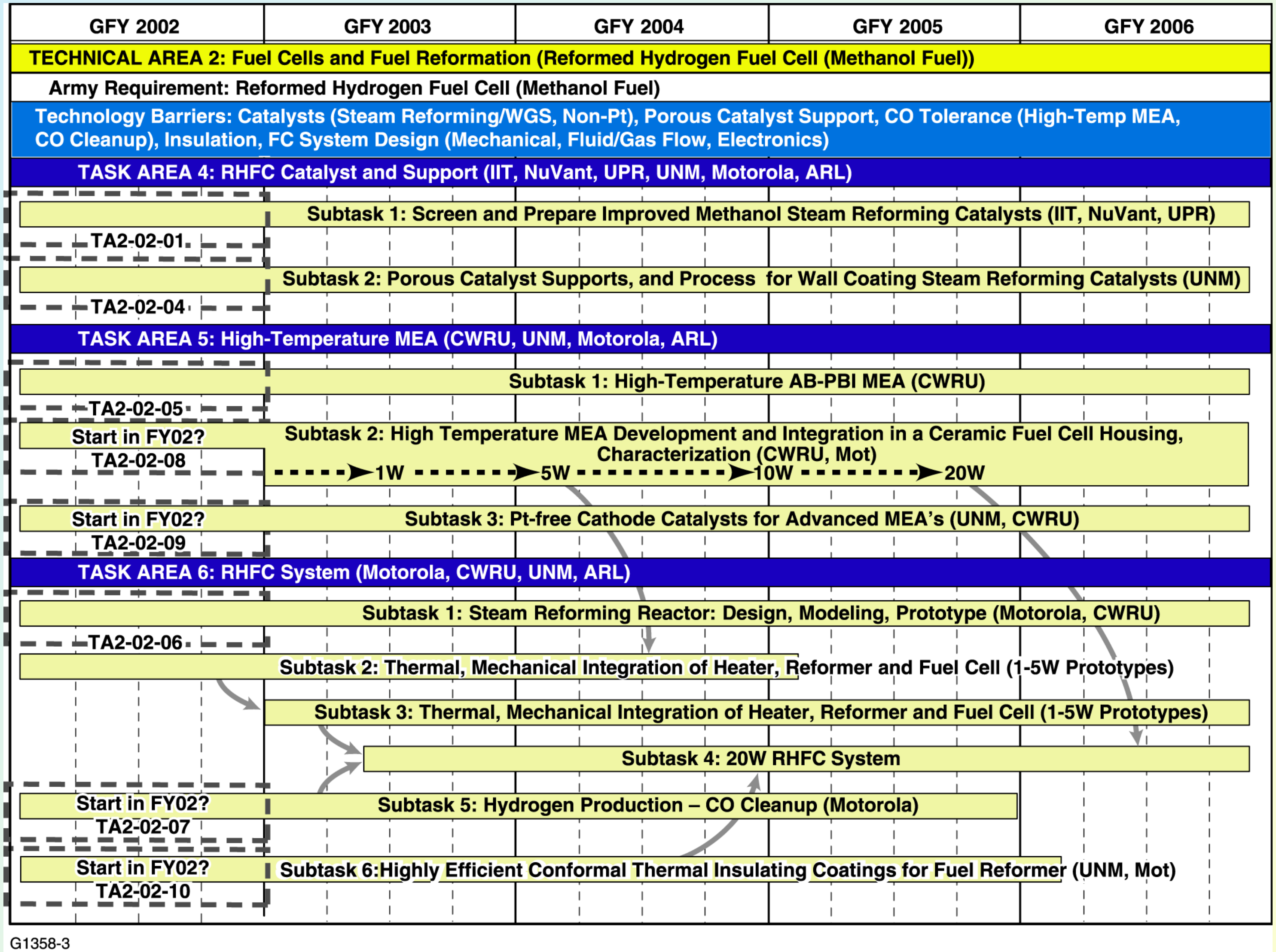
Solid Oxide Fuel Cell (SOFC) and Reformation

- Decreased fuel consumption and logistic burden
- Smaller sizes
- Increased range
- Increased power availability

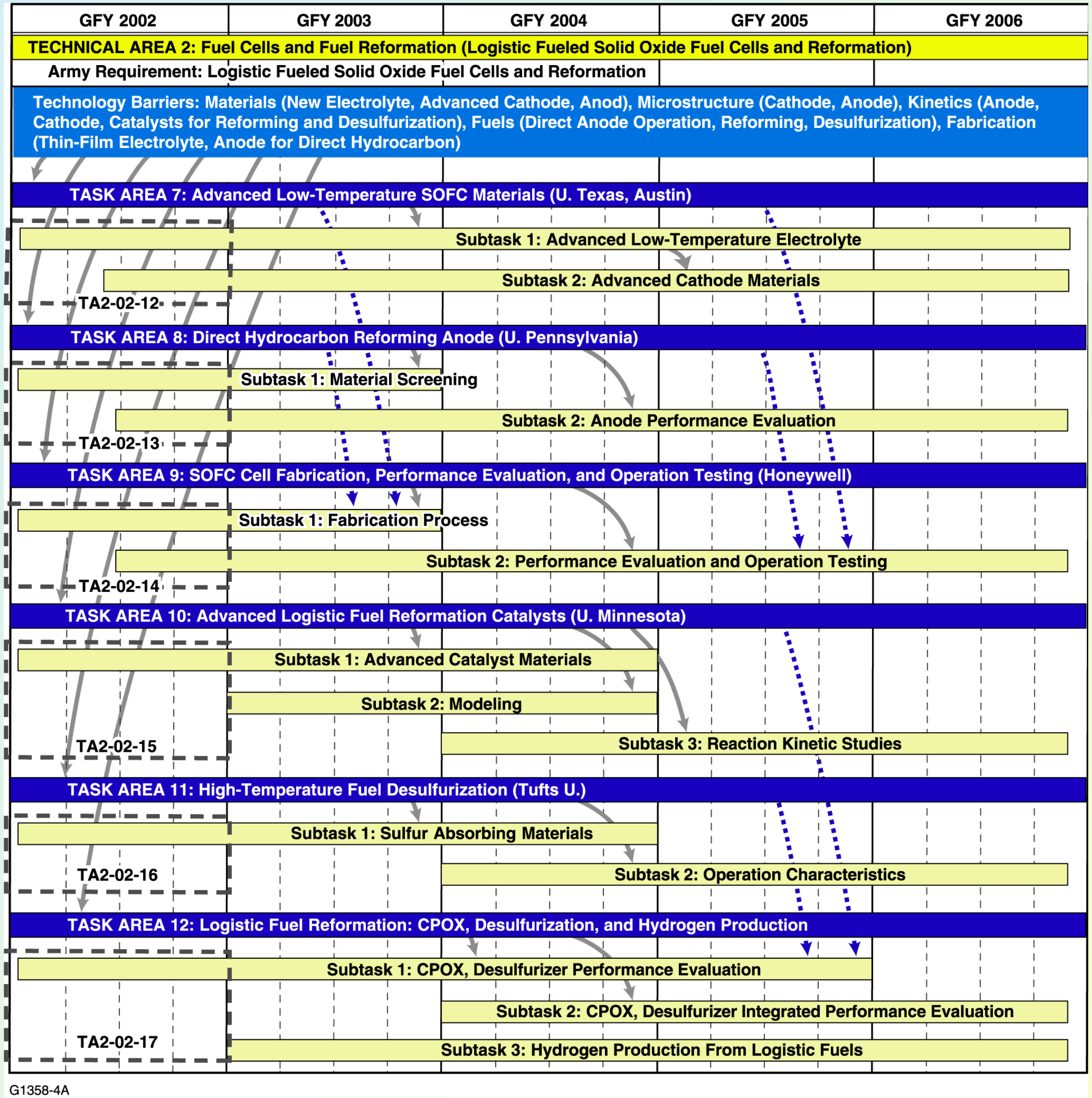
Fuel Cells and Fuel Reformation
DMFC Five-Year Research Roadmap



Fuel Cells and Fuel Reformation RHFC Five-Year Research Roadmap



Fuel Cells and Fuel Reformation
SOFC Five-Year Research Roadmap



Fuel Cells and Fuel Reformation FY '02 Annual Program Plan

Fuel Cells & Fuel Reformation

Motorola, Jerry Hallmark
Honeywell, Dr. Nguyen Minh
ARL, Dr. Deryn Chu

- DMFC Catalysts
- Polymeric Membranes
- DMFC Design, Model, Prototype
- RHFC Catalysts and Support
- High-temp MEA
- RHFC System

- Low-temp SOFC Materials
- Direct Hydrocarbon reforming anode
- SOFC Cell Fab, Eval, Testing
- Logistics Fuel Reformation Catalysts
- Hi-temp Fuel Desulfurization
- Logistics Fuel Reformation CPOX & Desulfurization

PEMFCs (DMFC, RHFC)

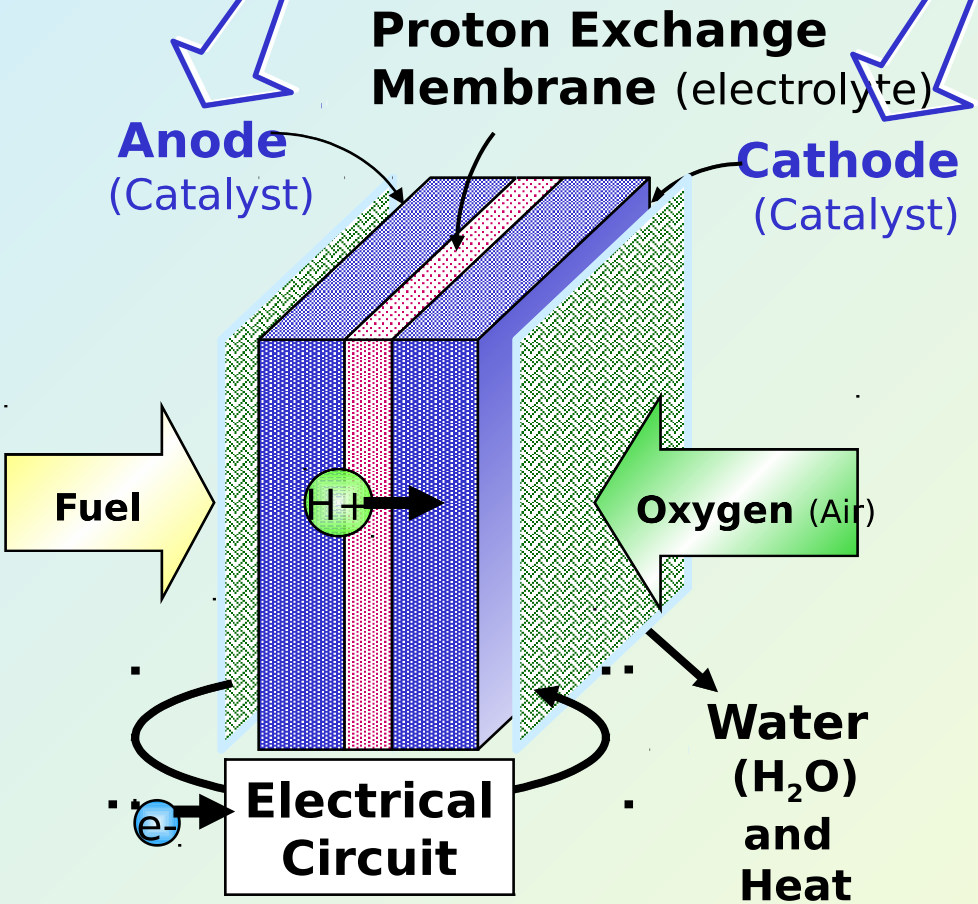
- Research on basic materials and components:
  - Catalysts & support, membranes
  - IIT, PSU, UPR, NuVant
- Research on system architecture and prototyping
  - DMFC/RHFC systems, peripherals, integration
  - Motorola

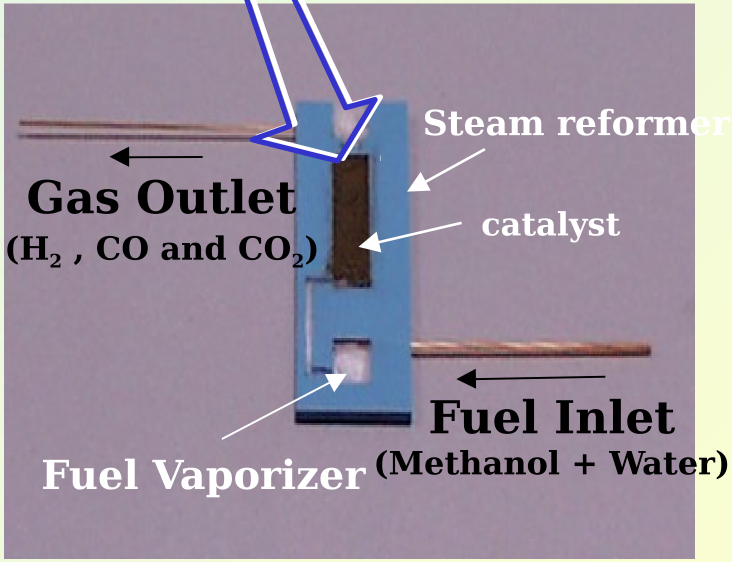
SOFC

- Research and development of advanced cell materials:
  - Direct oxidation anode - U Penn
  - Advanced Cathode - U Texas at Austin
  - High-temp sulfur sorbents - Tufts
- Performance evaluation of baseline systems:
  - SOFC fuel cell performance - Honeywell
  - Catalytic Partial Oxidation Reactor

Fuel Cells and Fuel Reformation Catalysts for DMFC & RHFC

- **Catalysts for Methanol Reformation and Fuel Cells (IIT/PSU/UPR/NuVant)**

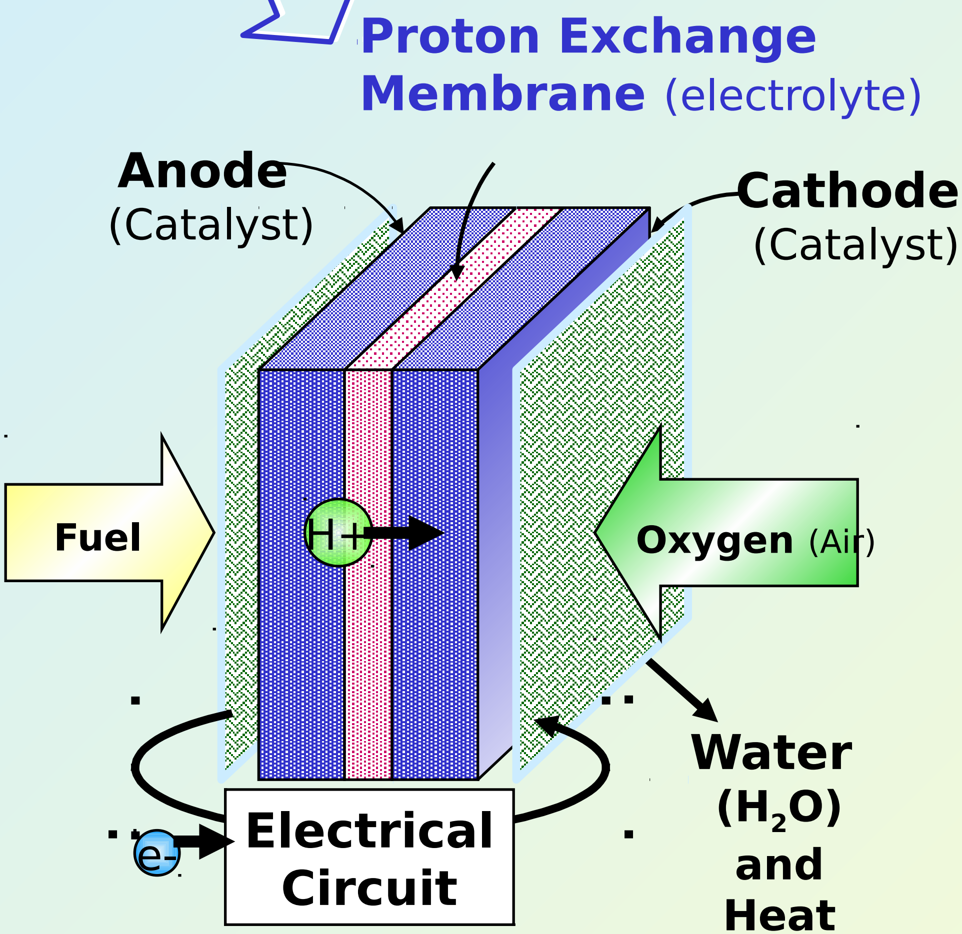




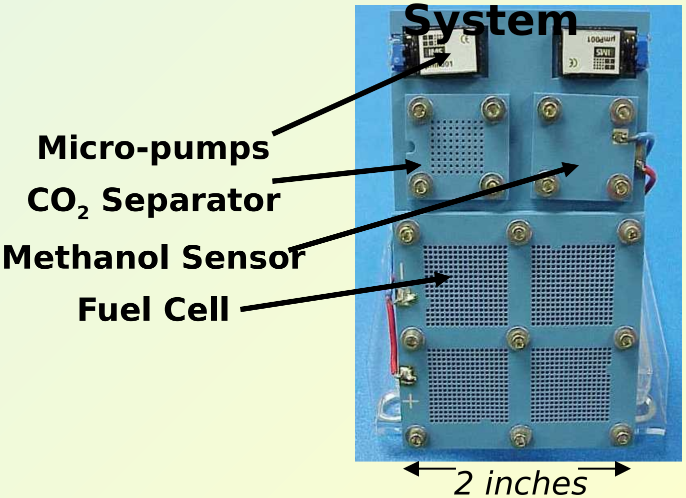
Size: 38mm x 13mm x 1mm
Capacity ~10ul/min

Fuel Cells and Fuel Reformation DMFC Tasks

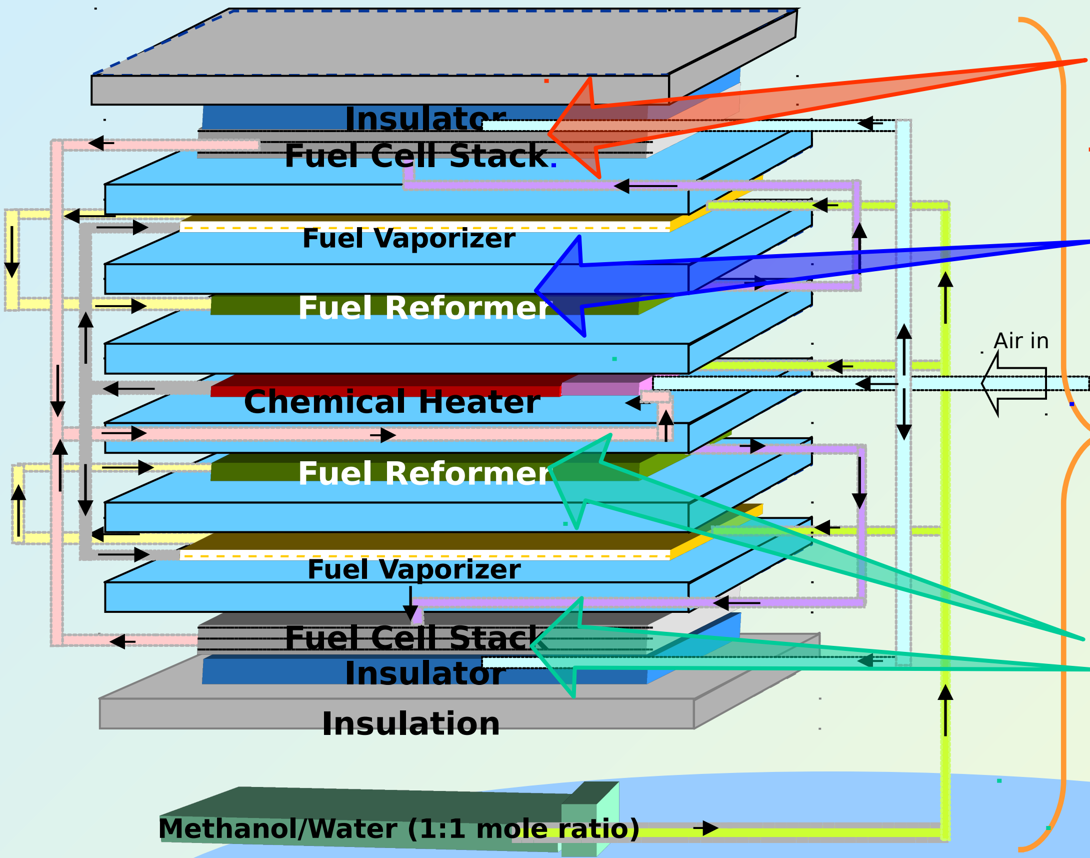
- DMFC Polymeric Membrane Synthesis (Motorola)
- DMFC System Design, Model, Prototype (Motorola)



Prototype Integrated 100mW Direct Methanol Fuel Cell System



Fuel Cells and Fuel Reformation
RHFC Tasks



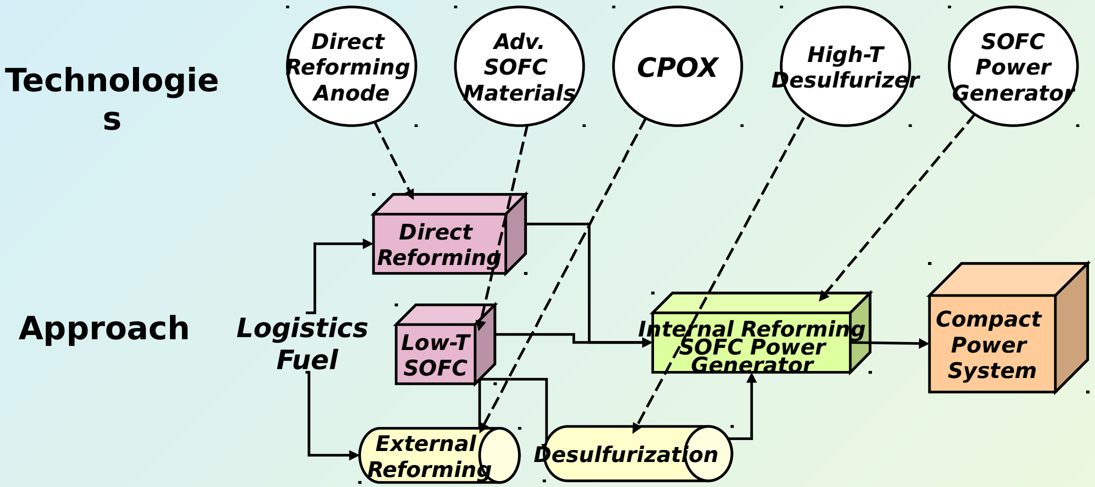
High Temperature AB-PBI MEA (CWRU)

Reforming Catalyst in Porous Support (UNM)

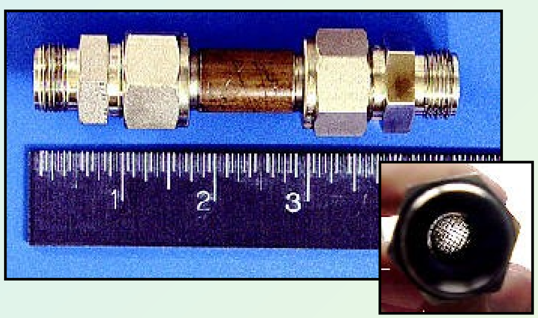
RHFC System Design, Model, Prototype (Motorola)

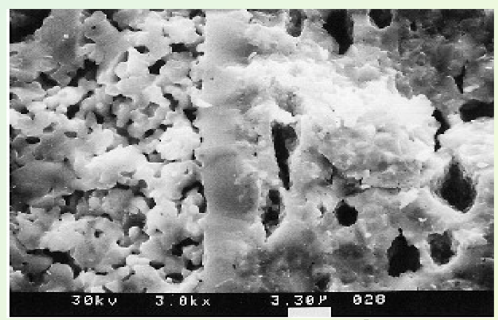
Catalysts for Reformation and Fuel Cells (IIT/PSU/UPR/NuVant)

Fuel Cells and Fuel Reformation
SOFC and Logistics Fuel Reformation

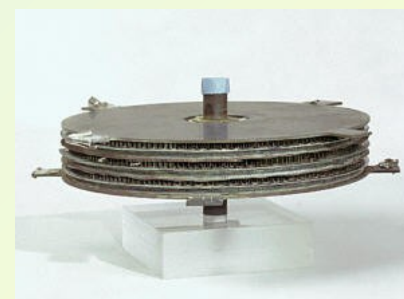


The SOFC runs on hydrocarbons or logistics fuel directly or hydrogen and CO generated from a fuel reformer, such as a catalytic partial oxidation reactor (CPOX)





$LaMnO_3$ Cathode | ZrO_2 Electrolyte | NiO/ZrO_2 Anode



CPOX rated for 1 kW SOFC stack **Fracture surface of SOFC cell** **SOFC stack**

Fuel Cells and Fuel Reformation
SOFC and Logistics Fuel Reformation
-Basic Research Team-

UNIVERSITY OF TEXAS AT AUSTIN → Low-Temperature SOFC Materials: Cathode and Electrolyte

Direct Oxidation Anode ← UNIVERSITY OF PENNSYLVANIA

TUFTS UNIVERSITY → High-Temperature Fuel Desulfurization

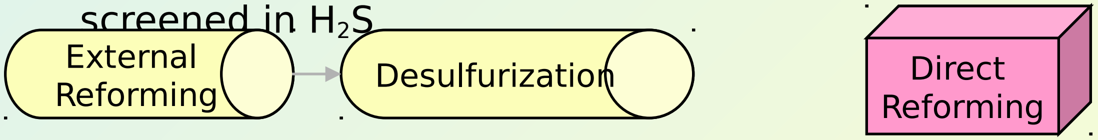
SOFC Cell Fabrication, Evaluation, Testing
Logistic Fuel Reformation CPOX & Desulfurization Evaluation & Testing ← HONEYWELL

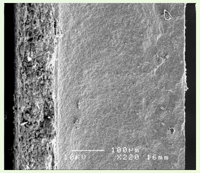
UNIVERSITY OF MINNESOTA → Logistics Fuel Reformation Catalysts

Fuel Cells and Fuel Reformation
Logistics Fuel Reformation & Direct Reforming
-Results to date-

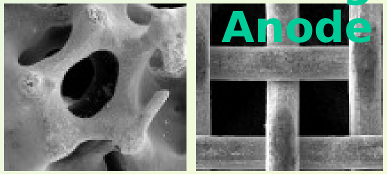
- **Direct Oxidation Anode**
  - Direct reforming in butene has been demonstrated
- **Logistics Fuel Reformation Catalysts**
  - CPOX system rapid startup (~10 seconds) has been demonstrated in decane
- **Logistics Fuel Reformation: CPOX and Desulfurization Evaluation and Testing**
  - CPOX reactor has been proof-tested in JP8 logistics fuel
- **High-Temperature Fuel Desulfurization**
  - Zirconia and lanthana doped ceria sorbents have been screened in H_2S

Parallel Strategy

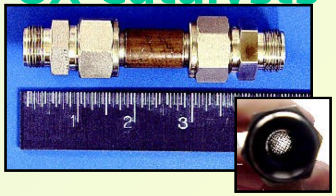




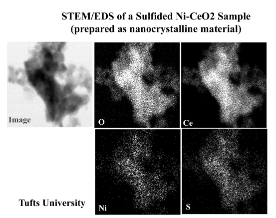
U. Pennsylvania
Direct Reforming Anode



U. Minnesota
Advanced CPOX Catalysts



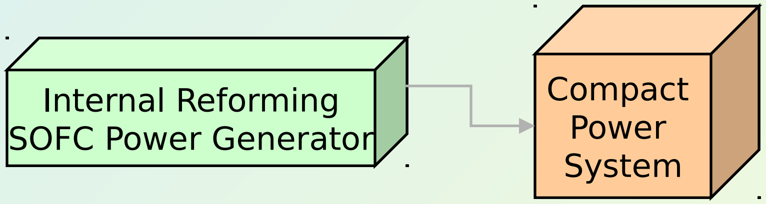
Honeywell
CPOX Testing/Integration

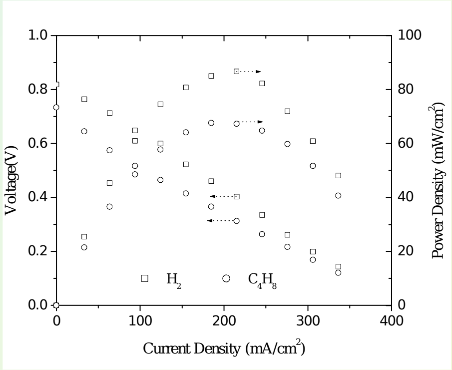


Tufts
High-T Desulfurization

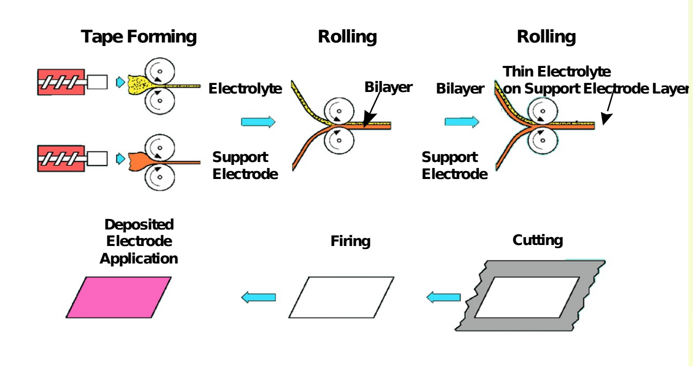
Fuel Cells and Fuel Reformation
Advanced SOFC Fabrication and Testing
-Results to date-

- **Low-Temperature SOFC Materials: Cathode and Electrolyte**
  - Demonstrated stability of LSGM electrolyte material the in presence of carbonaceous fuels
- **SOFC Cell Fabrication, Evaluation, Testing**
  - Electrochemical performance and sulfur tolerance of existing SOFC's has been mapped as a function of temperature





U Penn, U Texas Austin



SOFC Fabrication

Honeywell
SOFC Stack Testing

Fuel Cells and Fuel Reformation FY ‘03 Proposed Tasks

Fuel Cells & Fuel Reformation

Motorola, Jerry Hallmark
Honeywell, Dr. Nguyen Minh
ARL, Dr. Deryn Chu

- DMFC Catalysts
- Polymeric Membranes
- DMFC Design, Model, Prototype
- RHFC Catalysts and Support
- High-temp MEA
- RHFC System

- Low-temp SOFC Materials
- Direct Hydrocarbon reforming anode
- SOFC Cell Fab, Eval, Testing
- Logistics Fuel Reformation Catalysts
- Hi-temp Fuel Desulfurization
- Logistics Fuel Reformation CPOX & Desulfurization

PEMFC

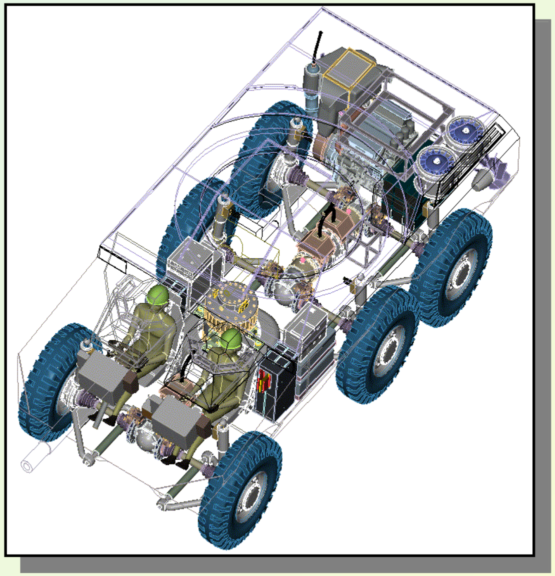
- Electrocatalyst screening & optimization
- DMFC Polymer Synthesis & Membrane Processing
- DMFC System: 1-2W System Optimization, Scaling?
- Methanol Reforming Catalyst in Microchannels
- High Temp AB-PBI, MEA Optimization
- RHFC System: 5W System Design, Model Prototype

SOFC

- Advanced anode optimization and testing
- Advanced low-temp electrolyte fabrication and testing
- CPOX output modeling
- SOFC- CPOX system integration
- High temp sulfur sorbent screening
- Evaluate hydrogen production from logistics fuels

P&E TA 3: Hybrid Electric Propulsion and Power

Objective: Provide enabling technologies supporting efficient, compact, light-weight energy conversion and electric power conversion and conditioning for FCS and robotic platforms.

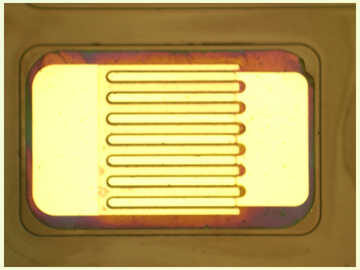


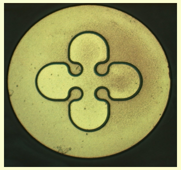
Challenges:

- Component temperatures and stresses
- Component level efficiencies
- Control architectures and algorithms
- Algorithms for fault protection
- High temperature insulators for SiC
- Ohmic contacts for SiC

Research Tasks:

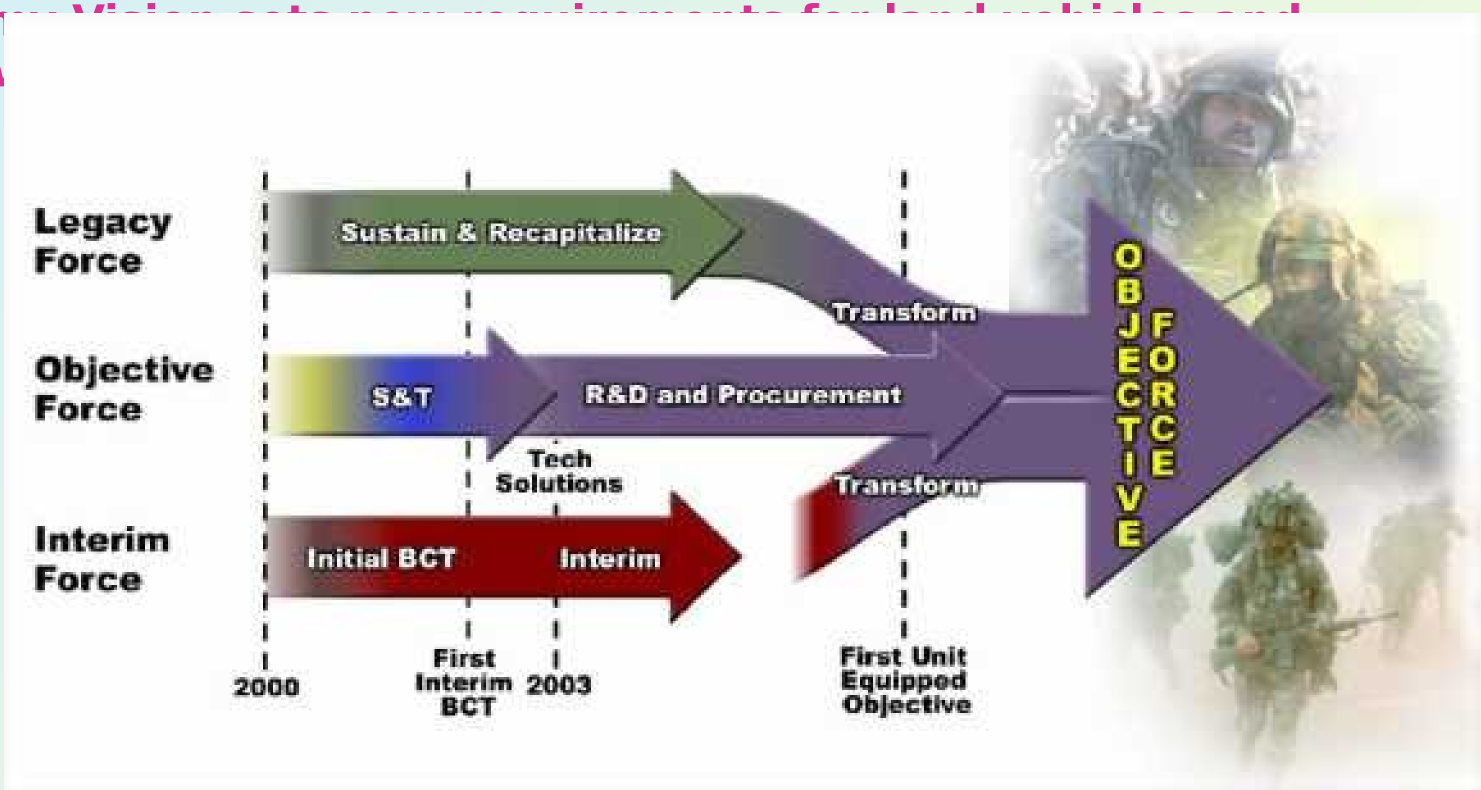
- High-speed Ceramic Turbogenerator Technology
- Turbo-electric Compounded Diesel Technology
- Matrix Converter Technology
- DC/DC Converter Technology
- SiC Materials/Device Technology
- Electric Machine Technology





Hybrid Electric Propulsion and Power
Why Hybrid-Electric Propulsion?

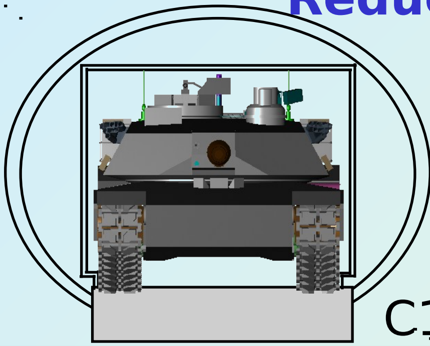
- Two major elements of the Army Vision for the Objective Force:
  - a strategically deployable, tactically superior and sustainable combat vehicle system
  - the dismounted war fighter
- Army Vision sets new requirements for land vehicles and pow



Hybrid Electric Power ENABLES The Future Combat System and Benefits the Land Warrior

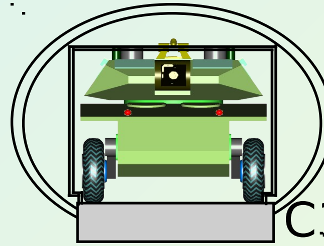
Hybrid Electric Propulsion and Power Objective Force Drivers

Reduce Combat Vehicle Size and Weight



C17/C5

Science & Technology



C130

Up to:
70% Lighter
50% Smaller

Current System
60-70 Tons
650 Cu. Ft. Internal Volume

Future Combat System Platforms
20 +/- Tons
300-400 Cu. Ft. Internal Volume

Provide Field Power for Land Warrior

Sustainability

- **Power: 12 Mission Hours**

Mobility

- **Slight Weight Decrease Over Current Soldier Load**

Hybrid Electric Propulsion and Power

Benefits of Hybrid Electric Power

Hybrid System Architecture Allows:

- Intelligent Energy/Power Management
- Advanced Electric Based Weapons
- Dynamic Armor, Active Protection, Countermeasures
- 30-40% Reduction in Fuel Consumption
- 30-40% Increase in Interior Volume

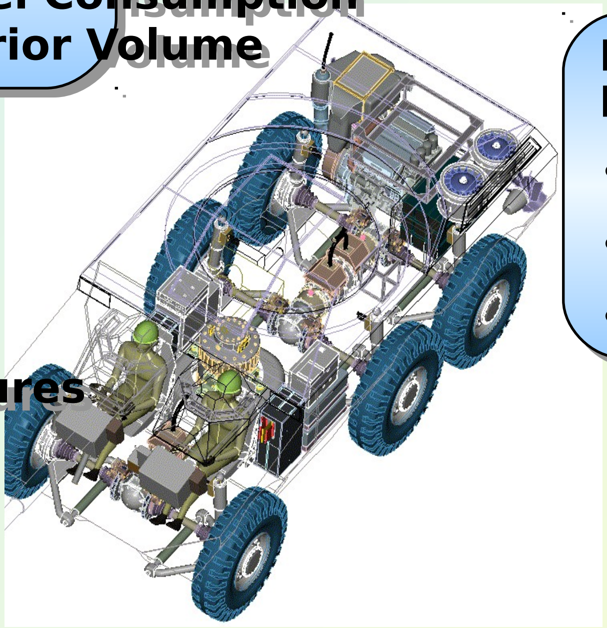
Multiple Propulsion/Power Source

- Allows Silent Watch & Mobility
- Enhances Dash Speed
- Ensures Battlefield Robustness

**Electrical Power for Platfo
Mobility/Agility Subsyster**

- Electromechanical Susp
- In-Wheel Propulsion
- Differential Torque Stee

**Notional Vehicle
(15 ton goal)**

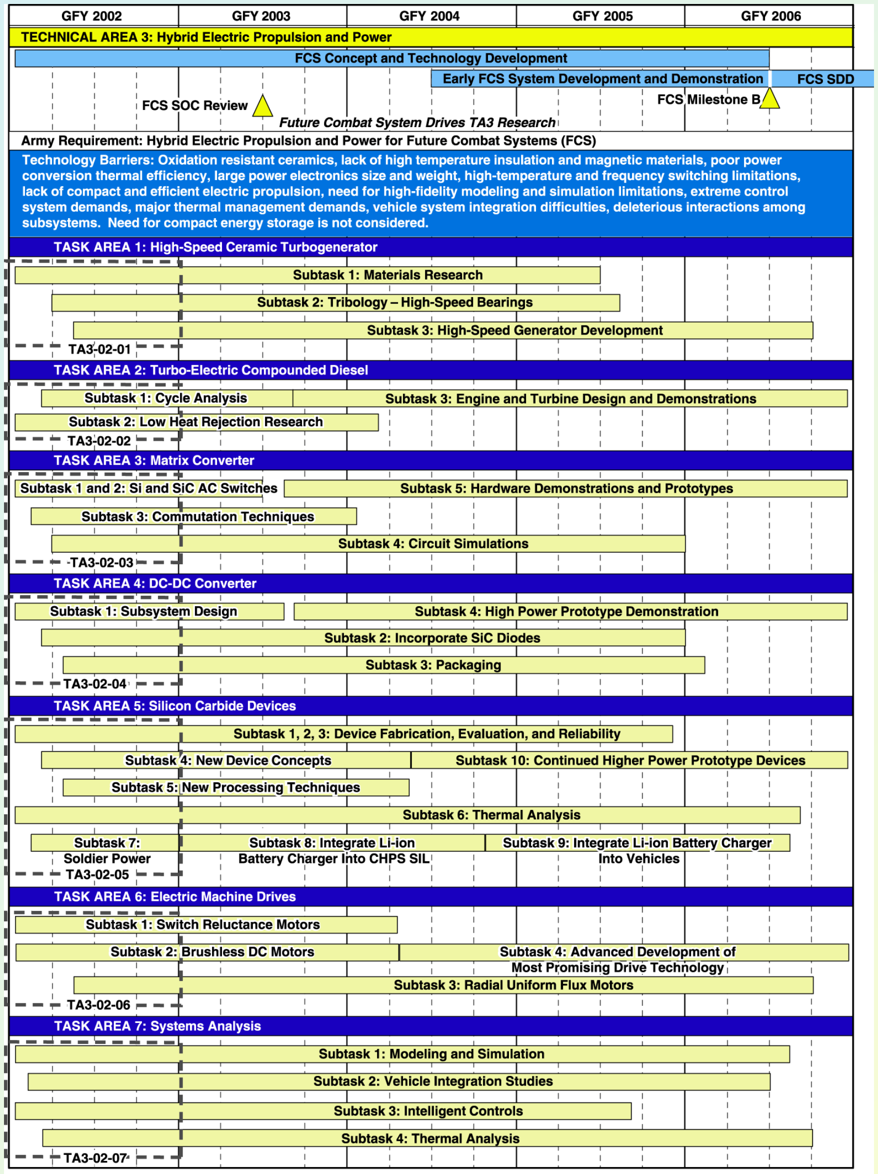


Reduced Signatures

- Acoustic
- Thermal
- Visual

Enabling Technology for Future Combat Systems (FCS)

Hybrid Electric Propulsion and Power
Five-Year Research Roadmap



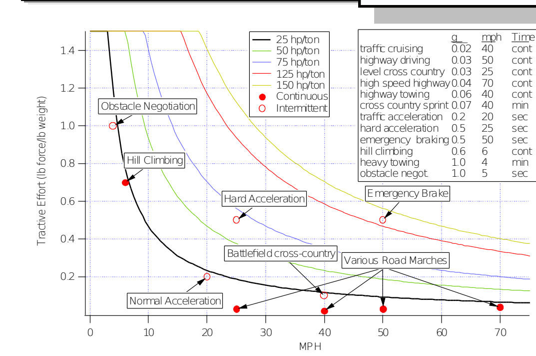
Hybrid Electric Propulsion and Power
FY 02 Annual Program Plan

Hybrid Electric Propulsion & Power

SAIC, George Frazier
Honeywell, John Meier
ARL, Dr. Ken Jones

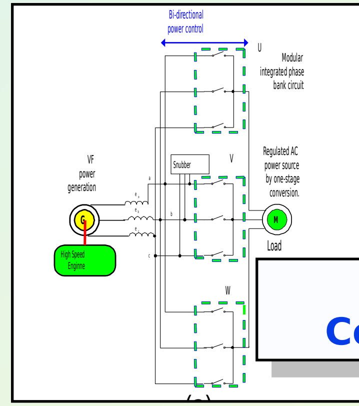
- Hi-speed Ceramic Turbogenerator
- Turbo-electric compounded diesel
- Matrix Converter
- DC/DC Converter
- SiC Materials/Devices
- Electric Machines
- Systems Analysis

Systems Analysis

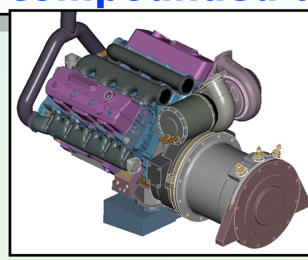


	g	mph	Time
traffic cruising	0.02	40	cont
highway driving	0.03	50	cont
level cross country	0.03	25	cont
high speed highway	0.04	70	cont
highway towing	0.06	40	cont
cross country sprint	0.07	40	min
traffic acceleration	0.2	20	sec
hard acceleration	0.5	25	sec
emergency braking	0.5	50	sec
hill climbing	0.6	6	cont
heavy towing	1.0	4	min
obstacle negot	1.0	5	sec

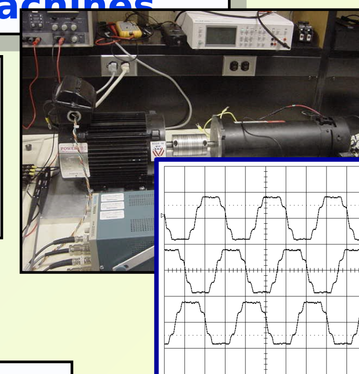
Matrix Converter



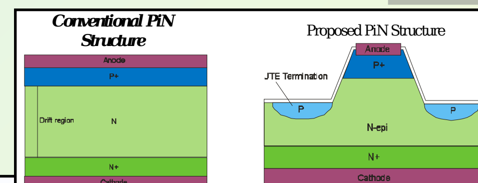
Turbo-electric compounded diesel



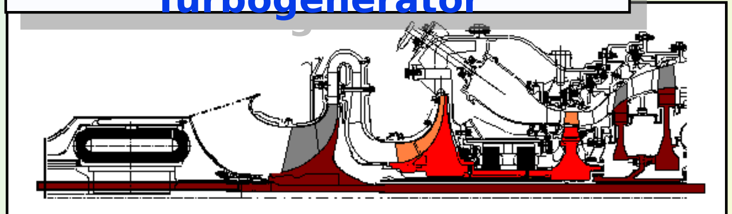
Electric Machines



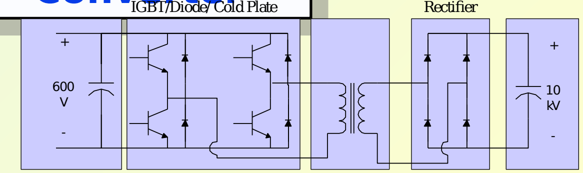
SiC Materials/Devices



Hi-speed Ceramic Turbogenerator



DC/DC Converter



Hybrid Electric Propulsion and Power Objectives, Challenges, Approach

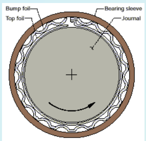
- Will develop advanced power conversion technologies to enable more compact and efficient combat hybrid electric vehicles
- Challenges for achieving these goals are overall system size and efficiency for a fieldable system
- Technical approach is multi-pronged
  - Investigate advanced, more compact & efficient power converters (i.e., engines & fuel cells and various combinations) which can utilize high sulfur logistics fuel
  - Improve the state of the art for SiC
  - Develop systems which effectively utilize both of above technology advances

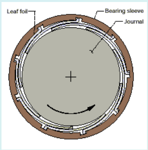
Hybrid Electric Propulsion and Power Research Plan

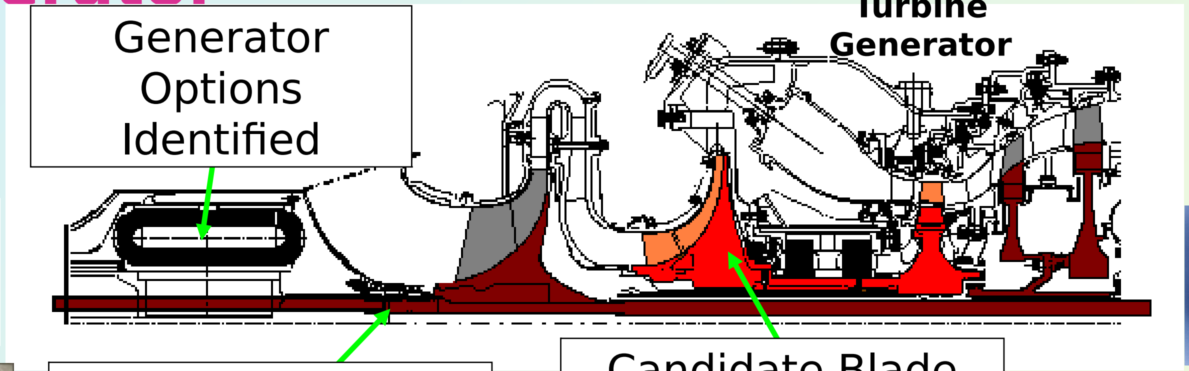
- Assess benefits and increase SOA for both a high speed ceramic turbo-generator and a turbo-electro compounded diesel
- Improve fabrication techniques and thermal management for SiC devices
- Develop test converter systems for utilization of SiC
  - Matrix converters
  - DC-DC converter
  - Motor drive converters and advanced motor designs
  - Validated models for performing designs with SiC devices
- System design and modeling to determine most promising insertions of these

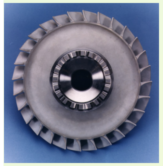
Hybrid Electric Propulsion and Power Engine & Generator Progress

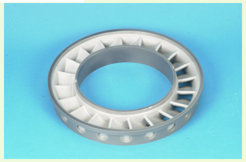
- **High Temperature Ceramic Turbo-Generator**



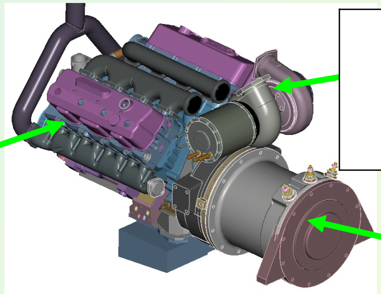




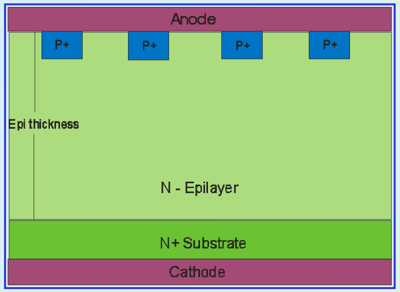




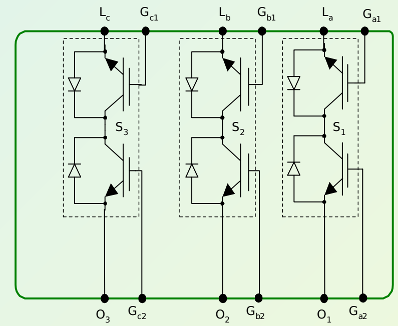
- **Electro-Turbo Compounded Diesel**



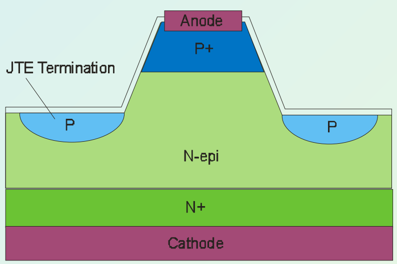
Hybrid Electric Propulsion and Power
Power Electronics Progress



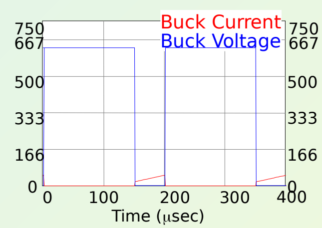
600 V SiC JBS Diodes
Fabricated & Being Tested

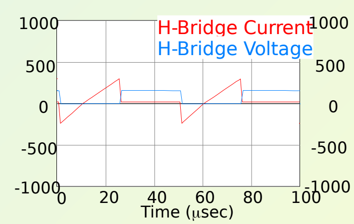


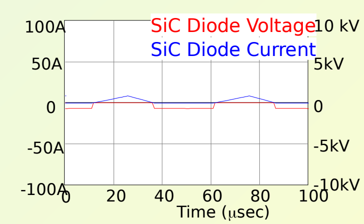
Vendor for Integrated 3 in 1
Matrix Converter Switch
Identified

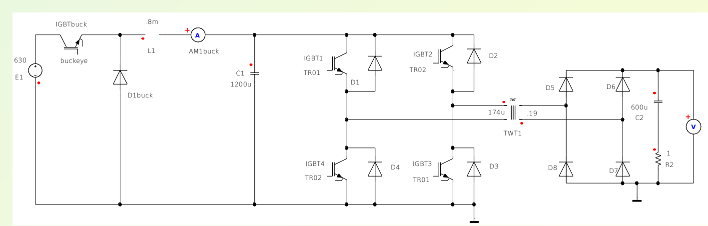


5 kV SiC pin Diode
In Fabrication





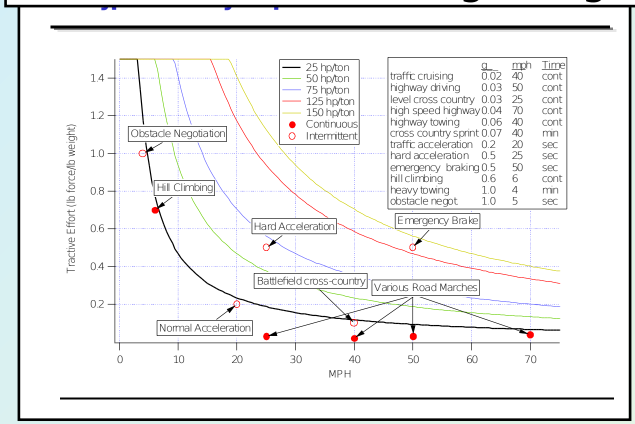


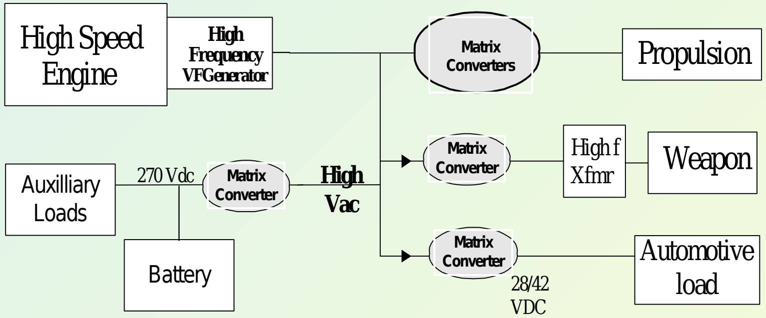


Preliminary DC-DC Converter Test Circuit
Analyzed

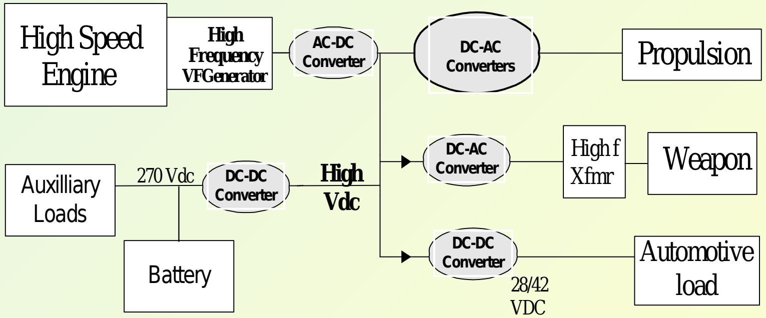
Hybrid Electric Propulsion and Power Machines & Systems Analysis Progress

Design Goals for Traction Motors Defined, Design Begun

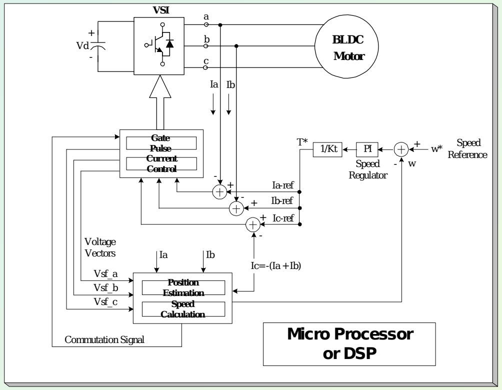




Comparison between Matrix Converter And DC Link Systems Begun



Motor/Controller for Reduced Torque Ripple of SRM Developed



Hybrid Electric Propulsion and Power FY 03 Preliminary Program Plan

Hybrid Electric Propulsion & Power

SAIC, George Frazier
Honeywell, John Meier
ARL, Dr. Ken Jones

- Hi-speed Ceramic Turbogenerator
- Turbo-electric compounded diesel
- Matrix Converter
- DC/DC Converter
- SiC Materials/Devices
- Electric Machines
- Systems Analysis

Systems Analysis

- Investigate Impacts of Advanced Components on System Based on Ongoing Research
- Develop Advanced Control Algorithms to Optimize the Systems

Matrix Converter

- Model SiC switches diodes for AC switch modules.
- Model SiC diode bi-directional switches for high current applications.
- Test SiC switching characteristics.

Turbo-electric compounded diesel

- Begin development if promising

Electric Machines

- Sensorless & Efficient SRM Drives
- Sensorless & Efficient PMBLDC Drives
- Optimize brushless DC generators
- Multi-converter hybrid power systems

SiC Materials/Devices

- 5kV, 10A epi-anode pin rectifier
- 600V, 40A planar JBS rectifier
- 600V, 15-25A BJT and/or DMOSFET

Converter

- ‘Charger’ duty cycle analysis
- Component integration and packaging
- Testing of SiC PIN diodes in converter
- Higher frequency/density transformer

Hi-speed Ceramic Turbogenerator

- Continue research leading to 300 kW Demonstrator

Other Accomplishments

Papers and Presentations

- **U Penn**
- **Penn State**
- **IIT**
- **MIT**
- **NuVant**
- **CAU**
- **U Puerto Rico**

- CHARACTERIZATION OF SDC ELECTROLYTE-SUPPORTED SOFCs FOR THE DIRECT OXIDATION OF HYDROCARBON FUELS *J. Electrochemical Society*
- COMBINATORIAL DISCOVERY AND OPTIMIZATION OF ELECTROCATALYSTS *Fuel Cell Handbook*
- DEVELOPMENT OF SUPPORTED BIFUNCTIONAL ELECTROCATALYSTS FOR UNITIZED REGENERATIVE FUEL CELLS *J. Electrochemical Society*
- ARRAY MEMBRANE ELECTRODE ASSEMBLIES FOR HIGH THROUGHPUT SCREENING OF DIRECT METHANOL FUEL CELL ANODE CATALYSTS *J. Electro Analy Chem Society*
- MULTI-STACK SILICON-DIRECT WAFER BONDING FOR 3D MEMS MANUFACTURING *J. Sensors and Actuators*
- A STUDY OF MULTI-STACK SILICON-DIRECT WAFER BONDING FOR MEMS MANUFACTURING *J. Sensors and Actuators*
- PRECISION FABRICATION OF HIGH-SPEED MICRO-ROTORS USING DEEP REACTIVE ION ETCHING (DRIE) Conference presentation, Hilton Head June 02
- SYNTHESIS AND STRUCTURAL CHARACTERIZATION OF A AU(I)-PYRAZOLATO TETRAMER *J. Chem.Soc., Chem. Commun.*
- THERMO-STRUCTURAL ANALYSIS OF A MICRO ELECTRO-MECHANICAL SYSTEM (MEMS)-BASEDGAS TURBINE GENERATOR STUDENT ORAL PRESENTATION, 16th National Association For Equal Opportunity in Higher Education (NAFEO) High Tech Student Expo 2002, Mar.02 Washington, DC.

Education and Curriculum Development

- **Clark Atlanta University**
  - **Initiated development of MEMS Lab with macro- and micro-structural experimental capabilities**
  - **Developing interdisciplinary materials science and engineering graduate program**
  - **Facilitating interdisciplinary undergraduate research**
- **University of New Mexico**
  - **Plan for expanded transport and reactor design curricula to include micro-reactor paradigms**
  - **Plan to develop summer research opportunities for undergraduates and high-school teachers**